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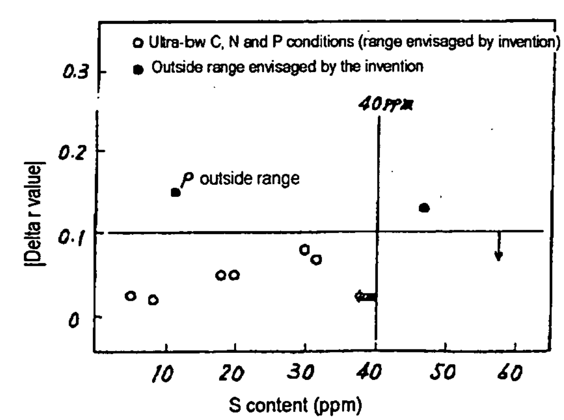
54 Title of the Invention

Hot Rolled Steel Strip Having Excellent Workability and Low Anisotropy, and a Method for the Manufacture Thereof

57 Abstract

Objective To provide hot rolled steel strip that simultaneously provides high ductility and low anisotropy and is highly resistant to secondary work cracking, and a method of manufacture of such hot rolled strip

Constitution Hot rolling is performed on raw material in which the C, P, N, S, Mn Al, and Si contents are controlled, and in which the diameter of the ferrite crystals is controlled, and in which the finishing temperature is not less than 910° C and in which the total reduction is not less than 90%, whereupon cooling is commenced within 1 second and the strip is cooled at a velocity of not less than 30° C/second to 650° C and the strip is coiled, providing hot rolled



steel strip that possesses excellent ductility and low anisotropy and is highly resistant to secondary work cracking

Claims

Claim 1 Hot rolled steel strip that possesses excellent workability and low anisotropy, and that contains
$C \leq 0.0025$ wt%
$P \leq 0.005$ wt%
$N \leq 0.003$ wt%
$Mn \leq 0.3$ wt%
$S \leq 0.004$ wt%
Al 0.005 wt% to 0.07 wt%
$Si \leq 0.03$ wt%
and other inevitable impurities, and that satisfies the requirement 40 ppm $\leq C + N + P + S \leq$ 110 ppm, and in which the diameter of the ferrite crystals is not less than GSNO (grain size number) 7

Claim 2 Hot rolled steel strip that possesses excellent workability as in Claim 1, such hot rolled steel strip further characterized by being manufactured by employing thin slab that has been cast in a belt type continuous slab casting machine

Claim 3 A method of manufacturing hot rolled steel strip that possesses excellent workability and low anisotropy, such method being characterized by the hot rolling of steel slab that contains
$C \leq 0.0025$ wt%
$P \leq 0.005$ wt%
$N \leq 0.003$ wt%
$Mn \leq 0.3$ wt%
$S \leq 0.004$ wt%
Al 0.005 wt% to 0.07 wt%
$Si \leq 0.03$ wt%
and other inevitable impurities, and that satisfies the requirement 40 ppm $\leq C + N + P + S \leq$ 110 ppm, at a finishing temperature of $\geq$910° C and with a total finishing reduction of $\geq$90%, and in which cooling is commenced within 1 second after rolling, and in which the strip is cooled at a velocity of not less than 30° C/second to a temperature of not more than 650° C and is then coiled

Claim 4 A method of manufacturing hot rolled steel strip that possesses excellent workability and low anisotropy as in Claim 3, such method further characterized by employing thin slab that has been cast in a belt type continuous slab casting machine

Detailed description of the invention

Relevant area of industry

The present invention relates to hot rolled steel strip that is employed in compressor casings and motor casings and so forth that require good workability and that also possesses low anisotropy, and to a method for the manufacture of such hot rolled steel strip.

Prior art

Hitherto, hot rolled steel strip has had poorer workability than cold strip, but hot rolled steel strip has been employed because it is difficult to impart workability to raw materials having thin strip thickness by means of cold rolling. Because it possesses poor drawability, when employed for products that are to be machined, its ductility is enhanced and its formability is improved. Moreover, when subjected to very heavy drawing, B is added in order to prevent cracking because it is subject to secondary work cracking.

The issues after forming are to reduce the waste that is generated in forming and to improve yields. Thus, when compressor casings and the like are formed, earing occurs if a highly anisotropic material is employed, increasing the amount of waste produced in shearing, while this must be taken into account in forming blanks necessitating the use of steel sheet of widths at least as great as the width required, which generates large amounts of waste. However, material to which B has been added is fundamentally more subject to earing, such that it is difficult for secondary work cracking and anisotropy to coexist.

In order to overcome this problem, JP2-209424 revealed a method of using ultra-low P steel without the addition of B in order to permit such coexistence, and with control of the crystal diameter through the use of a coiling temperature of between 550° C and 650° C. However, these days the requirements for raw materials are even more demanding, with users demanding simultaneously greater ductility, the absence of surface defects such as surface roughness and so forth, and also low anisotropy. It is impossible by the method of the prior art to consistently manufacture raw materials that simultaneously satisfy all of the requirements for fine grain sizes with ferrite crystals having GS numbers of not less than 7, with low anisotropy and also an absence of secondary work cracking.

Problems addressed by the present invention

The present invention overcomes these problems and provides hot rolled steel strip that possesses high ductility and low anisotropy, that does not produce secondary work cracking and that is free of surface defects, and a method for the manufacture of such hot rolled steel strip. Hence it is an objective of the

present invention to provide steel strip with a total[1] elongation of not less than 55% and a Δr value of not more than 0.1, and in which the grain size number of the ferrite crystals is restricted to not less than 7.

Means employed in order to overcome these problems

In order to achieve this objective, the present invention provides hot rolled steel strip that possesses excellent workability and low anisotropy, and that contains C $\leq$ 0.0025 wt%, P $\leq$ 0.005 wt%, N $\leq$ 0.003 wt%, Mn $\leq$ 0.3 wt%, S $\leq$ 0.004 wt%, Al 0.005 wt% to 0.07 wt% and Si $\leq$ 0.03 wt% and other inevitable impurities, and that satisfies the requirement 40 ppm $\leq$ C + N + P + S $\leq$ 110 ppm, and in which the diameter of the ferrite crystals is not less than GSNO (grain size number) 7, and a method of manufacturing hot rolled steel strip that possesses excellent workability and low anisotropy, such method being characterized by the hot rolling of steel slab that contains C $\leq$ 0.0025 wt%, P $\leq$ 0.005 wt%, N $\leq$ 0.003 wt%, Mn $\leq$ 0.3 wt%, S $\leq$ 0.004 wt%, Al 0.005 wt% to 0.07 wt%, and Si $\leq$ 0.03 wt% and other inevitable impurities, and that satisfies the requirement 40 ppm $\leq$ C + N + P + S $\leq$ 110 ppm, at a finishing temperature of $\geq$910° C and with a total finishing reduction of $\geq$90%, and in which cooling is commenced within 1 second after rolling, and in which the strip is cooled at a velocity of not less than 30° C/second to a temperature of not more than 650° C and is then coiled. In this invention, such hot rolled steel strip is manufactured by employing this slab that is cast by means of a belt type continuous slab casting machine.

Action

The inventors of the present invention initiated experiments based on the targets of the present invention which are a total elongation of not less than 55% in order to achieve high workability, a grain size number of not less than 7 as the GSNO of the ferrite crystals in order to prevent the occurrence of surface roughness, and to prevent the occurrence of secondary work cracking. As the first experiment, various tests were repeated in order to produce high ductility, and the effects of each of the elements were investigated. From these tests, it was determined that ductility could be enhanced by decreasing the levels of each of these elements. Of such elements, the effects of C, N, P and S were particularly[2] great, and it was determined that together they have a significant influence on the diameter of the crystal grains (see Figure 1 and Figure 2). However, it was also determined that it was impossible to satisfy the requirements for both total elongation of not less than 55% and a grain size number of not less than 7 with steel materials in which the content of these components was extremely low under normal hot rolling conditions.

Hence, the correlation between crystal grain diameter and elongation was examined in a second experiment in which high reduction rolling and rapid cooling immediately after rolling were added as conditions to the conditions

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[1] Apparent misprint in Japanese original 'pre-' for 'total'

[2] Apparent misprint in Japanese original corrected in English

of the first experiment. As a result, it was confirmed that, through the addition of these conditions, a crystal grain diameter could be achieved of such a level as to prevent the occurrence of surface roughness while maintaining ductility (see Figure 1 and Figure 2). Moreover, in high purity steel, the reduction in the levels of C and N in solid solution had the effect of eliminating the grain boundary strengthening effect, and thus facilitating the occurrence of secondary work cracking. However, when the results of many tests were assembled and reviewed, it was determined that steel materials in which the P content was reduced exhibited less secondary work cracking.

Moreover, as Figure 3 shows, S has a significant effect on anisotropy, and that, taking high purity steel as the base, it is necessary to control the level of S in the steel in order to obtain a Δr value of not more than 0.1.

The constituent ranges of the present invention were determined on the basis of the results of these experiments. A detailed description of the conditions for the constituents is as follows. C has a significant effect on ductility. Solid solution C and so forth in the crystal grains of cementite and ferrite that were generated always caused a reduction in ductility. Consequently, the level of C in the present invention is not more than 25 ppm. This is intended to as far as possible improve ductility, because, with equal or greater amounts of C, it is not possible to consistently achieve the desired high ductility and elongation of not less than 55%. N also has a significant effect on ductility, and the nitrides and N in solid solution formed degrade ductility, in the same manner as for C. Hence the level of N is restricted to not more than 30 ppm.

Next, the level of Mn is set at not more than 0.3% because of the risk of a loss of workability. Limits are imposed on the levels of P in order to enhance ductility and in order to reduce secondary work cracking. More particularly, the level of P must not exceed 50 ppm, in order to prevent the occurrence of secondary work cracking. The level of S is also a most important requirement of the present invention, and must be not more than 40 ppm in order to achieve a Δr value of not more than 0.1 because, as can be seen from Figure 3, when the levels of C, N and P are extremely low and within the constituent ranges described, increased levels of S lead to increased anisotropy.

When large amounts of Si are added, ductility is degraded and the Si leads to the formation of Si-Mn system inclusions, which are deleterious. Hence, the present invention imposes the condition Si $\leq$ 0.03%, at which there are no effects on ductility and no deleterious inclusions are formed. Al is important as a deoxidising element, and is also important in reducing inclusions in steel. More particularly, not more than 0.005% Al does not produce thorough deoxidation, and hence large amounts of inclusions are formed. However, if too much Al is added, costs are increased and there is a risk of adverse effects from precipitates formed at the rolling stage. Consequently, a range of from 0.005% to 0.07% is specified for Al.

In order to prepare materials that provide the high ductility envisaged by the present invention, it is necessary to impose an overall limit on the elements which produce significant effects in very small quantities. Figure 1 shows the correlation between the total levels of the extremely small amounts of C, N, P and S in the steel and total elongation, and Figure 2 shows the correlation between these elements and the crystal grain number (GSNO)[3]. As can be seen from Figure 1, it was confirmed that the restriction on the levels of the four elements present in extremely small quantities produced significant effects on ductility. Thus, the condition for improving ductility is 40 ppm $\leq$ C + N + P + S $\leq$ 110 ppm. In this case, the requirement for not less than 40 ppm is because a grain diameter of GSNO not less than 7 is not achievable, even under high reduction followed immediately by rapid cooling, as is evident from Figure 2. The upper limit of not more than 110 ppm is imposed because, at levels equal to or higher than this, the desired total elongation of 55% cannot be achieved, as is evident from Figure 1.

Next, as regards the hot rolling conditions, the finishing temperature in finishing rolling must be not less than 910° C in order to maintain the transformation ferrite grains in a uniform state when rolling is completed at not less than the Ar_3 transformation point. In compositions near to high purity steel such as those envisaged by the present invention, the transformation point is very high and the growth of the ferrite grains is very rapid. In such cases, the regulation of the coiling temperature alone is unable to consistently provide very fine grains with ferrite GS numbers of not less than 7. Consequently, the coarsening of the grains must be prevented through rolling and cooling. As a result of a detailed examination of such conditions, it was found that it was necessary to perform finishing rolling to a total reduction of not less than 90%, to cool the strip within 1 second of the completion of rolling at a velocity of not less than 30° C/second to not more than 650° C, and then to coil the strip, in order to render the γ grain diameter fine and as far as possible to restrict the growth of the transformation ferrite grains. By satisfying these conditions, it is possible to manufacture hot rolled strip that possesses high ductility and low anisotropy, and that does not develop secondary work cracking or surface roughness.

Practical embodiments

Table 1 lists the composition of the steel as tapped for the practical embodiments, and Table 2 lists the rolling conditions for the practical embodiments and the results of tests of material quality. Of the test materials Numbers 1 to 9 that were prepared according to the conditions envisaged by the present invention, material compositions A, B, C and D, which were within the ranges envisaged by the present invention, produced steel strip that exhibited the desired grain size number and elongation, Δr values of not more than 0.1, and that did not exhibit secondary work cracking. However, material E which

[3] Assuming misprint 'CSNO' for 'GSNO' in the Japanese original

had an excessive Mn content and material I which had excessive C + N + P + S content did not achieve the desired elongation. Moreover, material F which had excessive P content developed secondary work cracking. Material H which had excessive C + N + P +S content exhibited high elongation but excessively large grain diameters and exhibited surface roughness after working. Moreover material G which had excessive S content and material F which had excessive P content did not achieve the desired Δr values. In Table 2, 3' was direct rolled (DR) from a 50 mm thickness slab cast by means of a continuous slab casting machine, and 3" was direct rolled (DR) from an 80 mm thickness slab cast by means of a continuous slab casting machine; the results for both were satisfactory.

Next, Numbers 10 to 15 show the results of an examination of the manufacturing conditions for material A; in Number 10, the finishing temperature was too low; in Number 11, the reduction was too low; in Number 12, the cooling start time was too late; in Number 13, the cooling velocity was too low, and in Number 14, the cooling stop temperature was too high, and in all cases, the grain sizes were too large and surface roughness developed.

Table 1

wt%

Steel type	C	Si	Mn	P	S	Al	N	C + N + P + S	Classification*
A	0.0018	0.011	0.09	0.002	0.0032	0.054	0.0022	92	O
B	0.0005	0.015	0.05	0.002	0.0008	0.007	0.0011	44	O
C	0.0023	0.013	0.27	0.004	0.0018	0.045	0.0027	108	O
D	0.0009	0.017	0.16	0.005	0.0020	0.025	0.0016	95	O
E	0.0022	0.010	0.33	0.002	0.0030	0.068	0.0020	92	X
F	0.0007	0.016	0.12	0.007	0.0011	0.053	0.0013	101	X
G	0.0011	0.009	0.15	0.002	0.0047	0.052	0.0018	96	X
H	0.0005	0.005	0.01	0.001	0.0005	0.045	0.0010	30	X
I	0.0020	0.012	0.22	0.004	0.0035	0.036	0.0030	125	X

* O: Falls within range envisaged by the present invention

Table 2

No.	Steel type	Heating (° C)	Roughing		Finishing				Cooling start time (sec)	Cooling velocity (° C/ sec)	Cooling stop temp. (° C)	GSNO	El (%)	Δr value	2ary work cracking	Classification*
			Change in gauge (mm)	Temp. (° C)	Start temp. (° C)	End temp. (° C)	Reduction (%)	Strip gauge								
1	A	1250	250 - 43	1150	1100	920	93	3.0	1.0	50	600	7.3	59	0.07	O	O
2	B	1270	250 - 39	1150	1100	940	91	3.5	0.3	30	500	7.0	62	0.02	O	O
3	C	DR	250 - 36	1120	1030	910	95	1.8	0.7	60	550	7.5	57	0.05	O	O
3′	C	DR	-	-	1030	910	95	2.5	0.7	60	550	7.5	56	0.05	O	O
3″	C	DR	-	-	1030	910	97	2.4	0.7	60	550	7.4	55	0.05	O	O
4	D	1220	250 - 28	1170	1110	930	95	1.4	0.6	70	500	8.0	56	0.05	O	O
5	E	1200	250 - 32	1150	1120	920	90	3.2	0.5	50	600	7.0	53	0.08	O	X
6	F	1220	250 - 40	1150	1120	940	92	3.2	0.4	40	400	8.0	55	0.15	X	X
7	G	1230	250 - 44	1100	1050	930	95	2.2	0.7	40	400	8.0	55	0.13	O	X
8	H	1190	250 - 32	1120	1070	910	95	1.6	1.0	70	500	5.0	62	0.03	O	X
9	I	1240	250 - 28	1130	1080	920	92	2.2	0.7	40	500	7.5	54	0.08	O	X
10	A	1250	250 - 35	1140	1030	880	91	3.0	1.0	50	600	4.5	53	0.1	O	X
11	A	1240	250 - 25	1140	1090	910	88	3.0	0.7	40	550	6.0	60	0.09	O	X
12	A	1250	250 - 35	1150	1100	920	91	3.0	1.3	40	600	6.5	60	0.09	O	X
13	A	1230	250 - 35	1140	1100	920	91	3.0	0.8	20	500	6.0	59	0.08	O	X
14	A	1230	250 - 35	1140	1090	910	91	3.0	0.8	50	700	6.0	58	0.08	O	X
15	A	DR	250 - 43	1150	1100	930	93	3.0	0.7	50	550	7.5	58	0.06	O	O

* O: Falls within range envisaged by the present invention

Effects of the invention

The steel strip envisaged by the present invention possesses high ductility and low anisotropy, and does not exhibit secondary work cracking or surface roughness, and can be pressed under forming conditions that are not achievable with hot rolled strip of the prior art.

Simplified description of the drawings

Figure 1 is a drawing showing the correlation between the level of C + N + P + S in the steel and elongation.

Figure 2 is a drawing showing the correlation between the level of C + N + P + S in the steel and crystal grain size number.

Figure 3 is a drawing showing the correlation between S content in the steel and the Δr value.

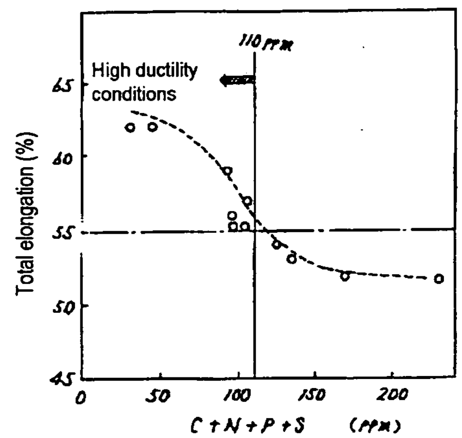

Figure 1

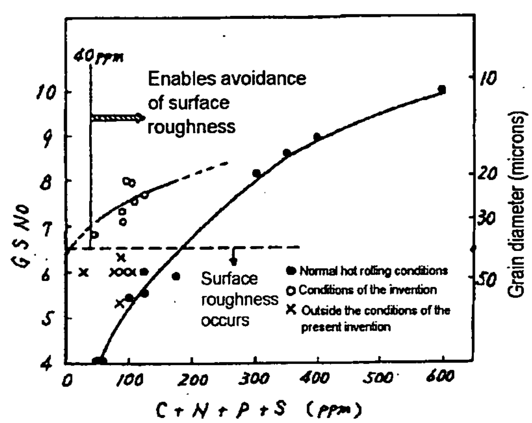

Figure 2

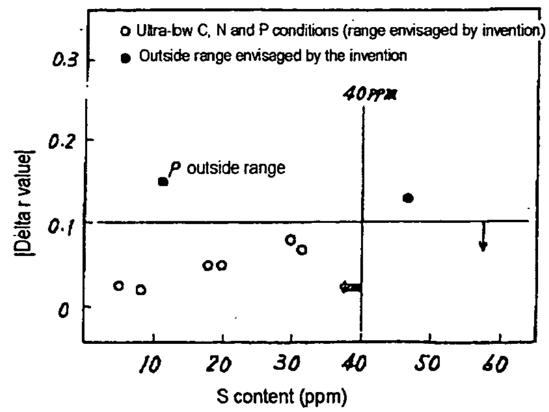
Ultra-low C, N and P conditions (range envisaged by invention)
Outside range envisaged by the invention
0.3
0.2
0.1
0
40ppm
P outside range
|Delta r value|
10
20
30
40
50
60
S content (ppm)

Figure 3